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ADVANCED AEROSPACE TECHNOLOGY DEVELOPMENT AT MSE TECHNOLOGY APPLICATIONS, INC.

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ABSTRACT

MSE Technology Applications, Inc. (MSE) is a multidisciplined technology company specializing in the research, development, engineering, testing, and evaluation of new technologies for application in the advanced energy and aerospace industries. MSE's customer base includes a broad sampling of U.S. federal agencies such as the U.S. Department of Energy (DOE), U.S. Department of Defense (DoD), and National Aeronautics and Space Administration (NASA). The aerospace research being conducted by MSE is very diverse and has the potential to be used in many different applications. These research and development (R&D) efforts focus on problems of high interest to NASA, the DoD, and the aerospace industry. The skill base that has been assembled by MSE provides the aerospace community with a resource that can be efficiently used to address high-priority technology development issues. The aerospace projects currently being conducted for NASA and the DoD represent some of the most advanced aerospace technology research in the Nation. Each of these projects possess the potential for revolutionary breakthroughs in various aspects of aerospace technology and could make routine commercial and military space operations feasible. This paper provides a summary description of these projects.

1. Magnetohydrodynamics Accelerator Research into Advanced Hypersonics (MARIAH) Program

The objective of this program is to develop the critical enabling technologies required for a advanced hypervelocity ground test facility. The proposed facility will be a one-of-a-kind, national test facility capable of simulating true air at velocities up to Mach 15. Both NASA and the DoD have determined that a need for such a facility exists for civil and military applications.

The primary purpose of this facility will be to test and evaluate the high-speed air-breathing engines (scramjets) required for future hypersonic flight vehicles. Development of these flight vehicles will require ground test facilities that can provide a continuous flow at Mach numbers of 8 to 15. Presently, there are no continuous flow facilities in the world capable of simulating air flows beyond Mach 8.

The planned facility will involve the integration of three stages. The first stage consists of a reservoir of air pressurized to approximately 22,000 atmospheres. This ultrahigh-pressure air will be released through a contoured nozzle causing significant velocity increase through the nozzle exit region. Beamed energy, in the form of electron beams, will pass through the gas as it exits the nozzle. This second-stage energy addition will heat air, thereby causing an increase in the total enthalpy. The third stage will consist of a magnetohydrodynamic (MHD) accelerator that will accelerate the air to the final required total enthalpy before it is passed through a second nozzle expansion and into the test section. Typical test hardware will consist of near full-scale, air-breathing engine modules and other components to be tested under Ahot@ combustion conditions (i.e., while burning hydrogen).

The high-pressure technology for the first stage, as well as the MHD technology for the third stage, was demonstrated in both the United States and Russia. The research must successfully address several critical technical issues before such a facility can be constructed (e.g., it is uncertain whether MHD can operate in the high-pressure regime characteristic of the exit flow from the high-pressure driver). Additionally, the issues relating to the second-stage beamed-energy addition region must be thoroughly investigated.

MSE initiated the first phase of this project in fiscal year (FY) 1995 under the direction of NASA Langley Research Center (NASA-LaRC). In FY98, sponsorship was transferred to the U.S. Air Force (USAF) under the direction of the Arnold Engineering Development Center (AEDC). Other participants include the Lawrence Livermore National Laboratory, Sandia National Laboratory, and Princeton University.

2. High-Lift Flight Tunnel Study

The High-Lift Flight Tunnel (HiLiFT) uses emerging high-speed magnetic levitation technology to propel a model cart through a pressurized, temperature-controlled test medium. A large-scale model will move through a pressurized, cryogenic tube to provide high Reynold=s number capability. Nitrogen is used as the test medium to provide the required low levels of turbulence and superior flow qualities. This facility will also have the potential for other types of research (i.e., acoustics, submarine hydrodynamics, and icing effects). NASA-LaRC selected MSE to lead this effort because of MSE=s experience in magnetic levitation (Maglev), MHD, and other aerospace technology research.

The following areas were identified as near-term priority tasks for the development of this subsonic ground test technology:

$Test Productivity Evaluation: A rudimentary system error model was used to evaluate system test productivity. Current available knowledge base data was collected and analyzed, and a conceptual system design was established to provide a systematic means of identifying and prioritizing all error sources. The end product for this task is the initial concept design, error analysis, and a recommendation for future research required to answer the higher priority error analysis results.

$Maglev Operation in a Cryogenic Environment: A comprehensive evaluation of the various magnetic levitation devices (attractive/repulsive superconducting) was conducted to verify the advantages, disadvantages, and tradeoffs for each Maglev method as applied to the HiLiFT concept. MSE examined these technologies and performed an evaluation of system response under cryogenic environments. This task also included data analysis and design of a pilot-scale cryogenic tube to test various Maglev systems.

$Aerodynamic and Electrical Analysis of Maglev Systems: This task involved the identification and employment of two or more sets of empirical data of representative Maglev cart systems. Equations developed by MSE as part of the NASA Marshall Space Flight Center (MSFC) Maglifter Project were used as a basis to analyze the aerodynamic forces (g-forces) of various systems. One or more specific electrical and physical configurations for the coils were selected to create a set of equations suitable for implementation as a computer code, thereby relating the force applied to the vehicle to the supplied power. The NASA code was modified and modularized to facilitate comparisons of different configurations and profiles.

3. Low-Speed Systems for Air-Breathing Hypersonic Vehicles

The objective of this NASA-LaRC sponsored task is to evaluate technologies for in-flight air separation that are applicable to hypersonic vehicles. For different launchers and different missions, major target parameters of the air separation process could be in the following ranges: oxygen concentration = 80%B99%, oxygen recovery factor h_{sep} = 0.55B0.85. Minimum requirements (= 80%, h_{sep}= 0.55) were obtained in the study of a vertical takeoff launcher with a liquid rocket engine combined with an air separation system (Ref. 1).

The first phase of the study on vortex tube (VT) technology for air separation was performed at the Kakuda Research Center of the National Aerospace Laboratory (NAL) in Japan (Ref. 2), where the research was aimed at obtaining the highest oxygen concentration possible. In this study, a maximum 98.7% was attained with $h_{sep} \doteq 5\%$. In the practical and interesting range of enriched air flow fraction, an oxygen concentration of 51%B64% was attained at $h_{se\ p}$= 30%B36%.

These low recovery results were improved in the second phase of the study with some refinements of the VT design parameters. The second phase of the air separation study was conducted at the University of Liege in Belgium as part of a Future European Space Transportation Investigations Program (FESTIP) Technology Study for the European Space Agency (ESA). This phase was primarily aimed at enhancing the oxygen recovery capability of the VT (Ref. 3).

Further enhancement of air separation with VT technology is the first priority of the ongoing study at MSE. NASA-LaRC imposed the following criteria for this study: 1) 90% product purity; 2) 50% oxygen recovery, and 3) system-specific mass (including precoolers) not to exceed 10 kilograms per second of air flow (Ref. 4). Commercial, as well as custom-designed VTs, are being tested in the current study. A factorial test plan has been underway for the past 3 years, and smooth control of the two-phase flow has been achieved. Figure 1 shows a VT configuration on the test bench.

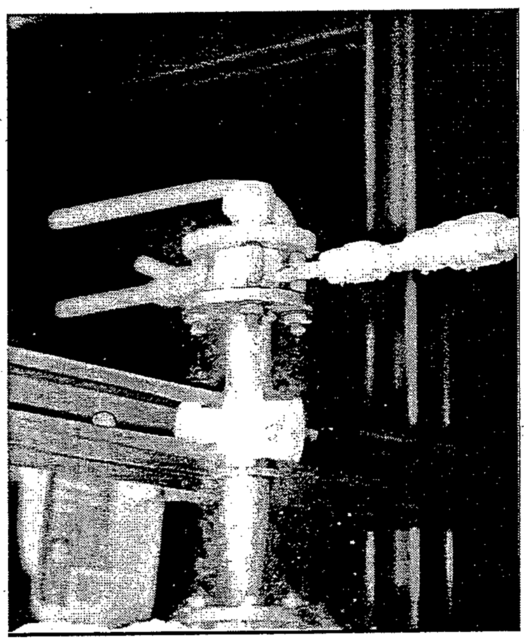

Figure 1. Vortex tube on the test bench.

Figure 2 presents a comparison of the test results with requirements for an air separation system. As Figure 2 illustrates, results to date are approaching the area corresponding to minimum requirements for an in-flight air separation system.

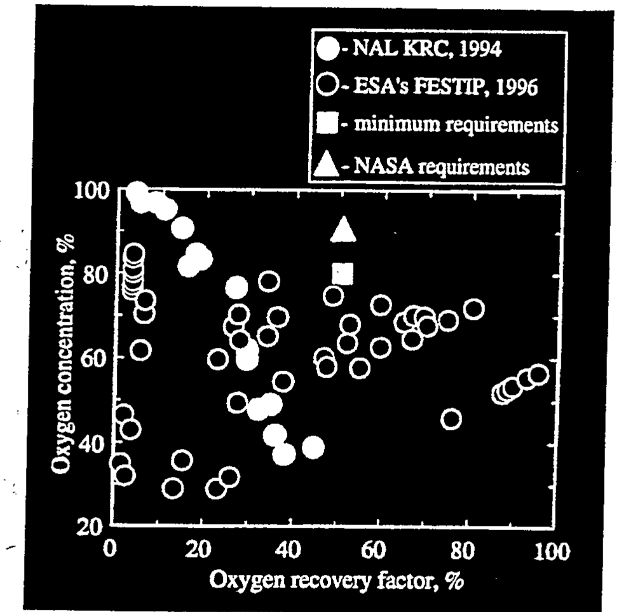

Figure. 2. Results of the air separation with

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<u>KLIN Cycle Propulsion Technology</u>

Development of KLINJ Cycle propulsion technology for a small single-stage-to-orbit (SSTO) launcher is currently under way for the USAF.

KLINJ Cycle application to vertical takeoff SSTO launchers is very promising. According to Reference 5, takeoff weight of the KLINJ Cycle-powered lifting body launcher is two times lower than that for an all-rocket launcher with the same mission. Dry weight of the KLINJ Cycle-powered launcher is 60%B70% of the dry weight of the all-rocket launcher. Figure 3 shows the configuration of the proposed KLINJ Cycle demonstrator.

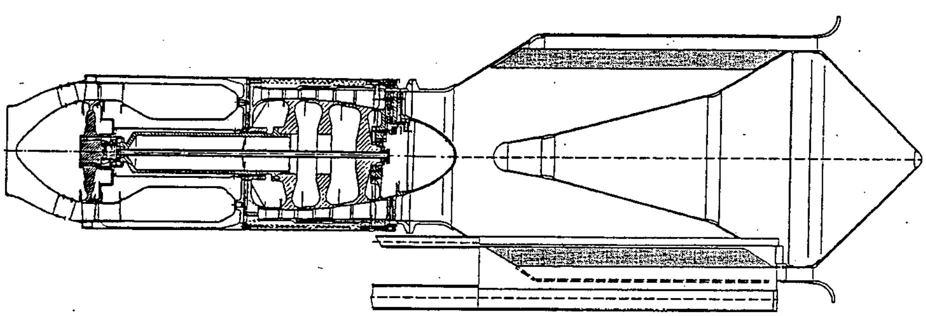

Figure 3. Subscale deep-cooled turbojet of the KLIN^{TM} Cycle.

4. Plasma Flow Control and Drag Reduction for High-Speed Vehicles

The objective of this NASA-LaRC sponsored research was to identify plasma-related methods for drag reduction and flow control during high-speed flight. Several different concepts have been suggested, including the air spike (both pulsed and continuous wave energy addition), preionization ahead of the bow shock, MHD flow control (application of magnetic fields plus seeding of the flow), and other schemes that rely on plasma-related techniques and technologies. It is critical to demonstrate that drag reduction and/or flow control can be accomplished in a manner energetically favorable and reasonable in terms of system consideration. Synergistic power generation during the process may also be possible. The project involved the following tasks:

$ Problem Definition: This task consisted of conducting critical activities to gain an understanding and to define the applicable physics. The activity involved two main subtasks including: 1) literature search and review in the area of glow discharges in high-speed flows, corona discharges in high-speed flows, shock wave/plasma interaction, and magnetic field/shock wave interactions; and 2) investigation of proposed mechanisms that may explain the changes in observed shock standoff distances, shock strengths, and widths between the discharge on/off modes as observed by others. An evaluation of the proposed mechanisms was then performed.

$ Analysis: This activity consisted of using available analytical methods and tools to conduct simulations of shock-plasma interactions. Tools such as the Ohio State University one-dimensional (1-D), nonequilibrium gas dynamics code, the Princeton University 1-D energy-addition model, and Florida State University=s computational plasma physics model were used for this effort.

$ Outside Review and Coordination: The purpose of this activity was to unite the project team members (as well as other outside experts) to review, critique, and evaluate the research activities.

$ Experiments: Experiments were conducted, and the results were documented. The initial experiments included shock visualization, measurements of shock standoff distance, and measurements of the pressure jumps across the shock. Data were collected with and without a glow discharge present. Additional experiments attempted to further refine and quantify the shock-plasma interaction phenomena, investigated the effects of using pulsed or continuous wave radio frequency sources for creating the glow discharge, investigated the directional effects, and studied the magnetic fields.

5. Electromagnetic Propulsion Concepts

The objective of this Small Business Innovative Research (SBIR) project is to further study an air-breathing horizontal takeoff and landing hypersonic vehicle design concept using an MHD energy bypass injector ramjet engine. Both the cruiser and space launch propulsion configurations are being investigated. The baseline configuration is a blended wing-body design. The integrated airframe/propulsion system can increase the hypersonic lift-to-drag ratio by as much as two units. This notional representation is an MHD configuration derived from a configuration concept that was defined in a 1997 study. The fuel is liquid/slush hydrogen combined with a liquid hydrocarbon.

There are two airflow-coupled MHD devices: 1) a nose unit that supports the energy necessary to reform the hydrocarbon fuel, and 2) a coupled MHD generator/accelerator used to bypass kinetic energy around the combustion chamber for Mach 6 and greater flight speeds. The result of bypassing flow energy around the combustion chamber is to maintain subsonic flow in the combustor. The MHD generator and accelerator use a liquid helium/hydrogen superconducting magnet (SCM) with a field strength of 8+-2 tesla (T). If liquid helium is used, a closed-cycle helium chiller is used to maintain the temperature of the magnet. Ground-based power is used to establish the initial electric current in the magnet coils.

6. Maglifter Technology Development

NASA-MSFC officials are currently planning for the development of Maglifter technology for use on earth-to-orbit (ETO) launch vehicles. MSE supported the overall NASA-MSFC effort by developing a computer code capable of modeling the magnetic levitation and propulsion subsystems required in an operational system and investigating the feasibility of MHD and other technologies as a Maglifter power source.

The development of the Maglifter computer code involved developing standardized, readily available and useable computer codes capable of performing the computations associated with system simulation of Maglifter launch systems, specifically in the area of magnetic levitation and propulsion. A set of design/off-design simulation studies to verify and validate the codes was conducted.

In addition to the development of the Maglifter computer code, MSE performed a conceptual study to assess the electrical propulsion and power converter system requirements necessary to accelerate a space launch vehicle from rest to approximately 600 miles per hour with magnetic levitation and linear armature motor accelerator techniques. A Maglifter track will more than likely be inclined, and the space launch vehicle will transfer to on-board propulsion once the vehicle leaves the track. A parametric study was performed to determine the required accelerator system energy input requirements and dynamics for different weight classes of vehicles.

The third activity for this project concentrated on the power supply technology to support accelerator systems. The power supply might consist of a combination of an MHD generator electrical energy source plus superconducting magnetic energy storage (SMES) systems along with the converter(s) necessary to supply the linear track accelerator motor.

7. Plasma Propulsion Development

The NASA Johnson Space Center (NASA-JSC) Advanced Space Propulsion Laboratory (ASPL) is a new facility dedicated to the experimental research of advanced space propulsion concepts. The laboratory features a 3.2-meter asymmetric tandem magnetic mirror machine configured for plasma propulsion studies using both electron and ion cyclotron resonance heating techniques. This Variable Specific Impulse Magnetoplasma Rocket (VASIMR) is a new tunable plasma propulsion system with a hybrid nozzle and is capable of variable thrust/specific impulse (I_{sp}) at constant power. These capabilities could enable rapid (approximately 4 months) transits to Mars by virtue of continuous modulation of the rocket exhaust. NASA-JSC officials believe the development of this technology will have a strong positive impact on human interplanetary travel and other missions of exploration. The research also focuses on high-power generation and conversion systems for space applications, as well as new applications in superconductivity.

MSE's support of the project involved the modeling and simulation of the MHD flow and interactions within the VASIMR device, including the hybrid magnetic nozzle. This magnetic nozzle will utilize a tailored magnetic field arrangement, as well as an annular hypersonic neutral gas blanket. The neutral gas blanket forces plasma-field detachment at the nozzle exhaust by plasma cross-field collisional diffusion.

Additionally, the exhaust field arrangement will be capable of alternating current (ac) modulation to further induce tearing instabilities, forcing the plasma to detach from the field at the exhaust under all conditions.

MSE developed a new code to study these aspects of the VASIMR system. The code has been delivered to ASPL, and it is currently being used to support further development of the concept.

8. Mass Injection and Precompressor Cooling Propulsion Technology

The high cost of access to space represents a severe constraint in making routine space operations a reality. One possible approach to address this problem involves the use of compressor precooling resulting from inlet oxidizer mass injection into an afterburning turbojet (TJ) propulsion system. An afterburning TJ engine modified in this way could serve as the propulsion for the first stage of a reusable launch system, and the compressor precooling resulting from inlet oxidizer mass injection would allow a TJ engine to fly to higher Mach numbers and altitudes.

MSE is developing mass injection and precompressor cooling (MIPCC) propulsion technology for the Defense Advanced Research Projects Agency (DARPA). The objective of this research is to develop the main principles and identify the enabling technologies required to apply the MIPCC concept as a first-stage propulsion system for the DARPA Responsive Access, Small Cargo, and Affordable Launch (RASCAL) Demonstration Program. This propulsion concept has the advantage of directly using the significant technical and economic investments made in TJ engines during the past 60 years. Assuming the reusable first stage of a launch vehicle using this technology is badically a high-speed aircraft with a modified engine, this approach allows the concept of operations of the launch vehicle to evolve from aircraft operations.

Mass injection of cryogenic oxidizer or expansion of compressed oxidizer could be used in existing TJs in the same way as water injection has been previously used for precooling to high Mach numbers and thrust enhancement. The use of an oxidizer for precooling also has the advantage of allowing the TJ combustor to remain in operation to higher altitudes. The use of cryogenic propellants could potentially allow for conventional staging of the Mach number, with precooling progressively increased with increasing Mach number and altitude where humidity will be low (avoiding icing effects). As the Mach number altitude increases, the injection of cryogenic propellant can be added to precool the compressor, increase engine thrust, and keep the combustor lit. As more mass is added to the flow, more fuel can be added to the combustor, again increasing thrust. Additionally, the addition of oxidizer to the flow will result in more oxygen in the afterbruner, thereby allowing the engine to produce additional thrust.

9. Pulsed-Detonation Rocket Engine Technology

The pulsed-detonation rocket engine (PDRE) is based on the repetitive generation of detonations in a chamber filled with combustible gases. The detonation is an efficient combustion process that can provide significant improvements in engine performance (I_{sp}). Each cycle of the PDRE operation consists of an injection phase where the chamber is being filled with a mixture of combustible gases, an ignition phase where the detonation is initiated, and a blowdown phase where the hot combustion products are being evacuated from the chamber. Maximim performance is achieved when each phase is optimized. This requires technology development in the areas of rapid valving, mixing, and ignitor design. In the case of high altitude and space propulsion, the PDRE presents an additional challenge as compared to air-breathing pulse detonation engine (PDE) technology. The chamber must be able to confine the fresh mixture for a time sufficient for the detonation to propagate through the chamber. Therefore, it is necessary to develop a valving technique that can contain the gases in the chamber during refill, without creating significant losses in performance during the ignition phase when the detonation wave is propagating through the chamber at high speed.

MSE performed the Computational Fluid Dynamic (CFD) modeling of the PDRE system under subcontract to the United Technologies Research Center (UTRC). Other participants included the Pratt & Whitney Engine Division of United Technologies Corporation, Boeing-St. Louis, NASA-MSFC, and NASA Glenn Research Center (NASA-GRC).

10. Efficient Power Generation From Pulsed-Detonation Engines

MSE has been awarded an SBIR contract from the Missile Defense Agency (MDA), formerly known as the Ballistic Missile Defense Organization, to investigate the concept of using a combination of a PDRE with an MHD generator for power generation in space. The novel PDRE-MHD concept has the potential for higher power generation performance (compared to a more conventional rocket-MHD system), as well as higher propulsion performance than the rocket-based system. Based on the repetitive detonation of seeded propellants and their subsequent expansion into a nozzle/generator, the concept uses multiple tubes arranged symmetrically and fired synchronously. In addition to the higher performance, the design is failure tolerant, robust, and low cost. It allows the deployment of clusters of satellite-based weapons, thereby increasing the survivability of a defense system. In addition to its ability to deliver the power required for directed energy weapons (DEWs), the PDRE-MHD system also provides for an efficient orbit maneuvering capability. This dual-use capability extends the operational range of the weapon platform, thereby allowing it to evade attack and increase the coverage for missile defense or space-to-air/space-to-ground attacks. The technology is also applicable to advanced space propulsion and ground-based power generation, giving it significant commercial potential.

The Phase I study successfully demonstrated the potential of the technology and its efficiency. Furthermore, a preliminary design of the complete power generator was achieved. In Phase II, MSE is continuing the development and optimization of the technology, as well as refining the engineering design. In addition, an experimental demonstration of the technology will be completed during Phase II, in addition to a systematic investigation of the key design parameters.

11. Fuel Cell Technology Development

NASA has identified water vapor emission into the upper atmosphere from commercial transport aircraft, particularly as it relates to the formation of persistent contrails, as a potential environmental problem Since 1999, MSE has been working with NASA-LaRC to investigate the concept of a transport-size emissionless aircraft fueled with liquid hydrogen combined with other possible breakthrough technologies. The goal of the project is to significantly advance air transportation in the next decade. The energy and propulsion system would be based upon hydrogen fuel cells (HFCs) powering electric motors, which drive fans for propulsion. The liquid water reaction product is retained onboard the aircraft until a flight mission is completed.

This investigation is currently focused on the following research areas: 1) revolutionary and innovative aeronautical concepts for transport-size aircraft (e.g., strut-braced-wing configuration and/or fuselage riblet film to achieve higher lift-to-drag ratio); 2) system-level analysis to investigate and determine the power density, size, and volume, pressure, temperature, and efficiency characteristics of state-of-the-art HFC systems; and 3) investigation of ultra-lightweight materials, including carbon nanotubes.

12. Conclusion

MSE is providing NASA, the DoD, and the aerospace industry with a new and highly capable aerospace technology development resource. MSE has quickly become a recognized leader in several important aerospace technology areas, and its staff of scientists and engineers is becoming internationally recognized for its expertise and capabilities. The aerospace technologies being developed by MSE could result in major advances in the areas of hypersonics, space transportation propulsion and power, and space exploration. As interest in routine commercial and military space operations grows, each of these technologies will become more important.